Texture and Storage Stability of Processed Beefsticks as Affected by Glycerol and Moisture Levels

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ABSTRACT

Ground beef-based beefsticks were produced with glycerol levels of 0, 2, and 4%, and dried to water activity levels of 0.90 and 0.85. Samples were analyzed by uniaxial compression and colorimetry after production and after 52°C storage for 1, 2, 3 or 4 wk. Deformability modulus, percent recoverable work, relaxation properties, and relative lightness were calculated. Glycerol, as well as water, acted as an effective textural plasticizer. Reductions in modulus and relaxation parameters due to glycerol addition were in the range of 30–40%. Glycerol can thus effectively be used to adjust physical properties without compromising stability. Higher moisture samples were relatively more elastic, as determined by recoverable work. High temperature storage reduced modulus, solidity and percent recoverable work (20–70%) in all samples.

Key Words: beefstick, shelf stable, glycerol, plasticization

INTRODUCTION

PROCESSED SAUSAGE OR JERKY-TYPE PRODUCTS ARE POPULAR snack items, and such portable and shelf-stable foods are necessary as operational rations for the military. One such item under development is a shelf stable meatstick, in which water activity is controlled by adjustment of moisture and incorporation of humectants. Glycerol is an effective additive for control of water activity (Linko et al., 1985) and has been studied as a preservative for intermediate moisture meats. Immersion in glycerol solutions lowered the water activity of smoked beef (Okonkwo et al., 1992a, b), restructured beef (Boyle et al., 1993), and buffalo (Prabhakar et al., 1992). Similarly, direct incorporation of glycerol into frankfurters reduced water activity (Lacroix and Castigne, 1985).

Adjustment of either water or glycerol level has textural effects, because both substances can potentially plasticize the protein matrix. These ingredients, as low molecular weight constituents, can interrupt the proteinaceous network and increase molecular mobility, thus "softening" the meat structure. The influence of moisture as a ubiquitous plasticizer has been extensively reviewed (Levine and Slade, 1992). Also, glycerol has been an effective plasticizer in certain protein systems (Kalichevsky et al., 1992). Lowering water activity by reducing moisture content will produce harder meatstick products, but incorporation of glycerol, in addition to assisting in control of water activity, may counteract any toughening effects of reduced moisture.

Processed beefsticks were produced at high and low water activities and with different levels of glycerol. Our objective was to determine effects of moisture and glycerol content on mechanical properties, measured by deformability, relaxation, and elasticity tests, using uniaxial compression. Changes in texture during accelerated storage were also determined, as was relative tendency to darken.

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MATERIALS & METHODS

Sample production

Three peppercorn flavor, beefstick batches (Table 1) were produced (formulas differed in glycerol level, varied to comprise 0, 2, and 4% of final weight). The samples (~1.8 cm in diameter and 10 cm long) were processed at facilities in the Iowa State University Food Science Department. Beef (bottom round) was trimmed (finished product fat content was ~25%), ground, blended with all other ingredients, and stuffed into 23mm collagen casings. The meatsticks were held at 10°C for 2h, then placed in a thermal processing chamber (41°C and 95% RH) for 18-24h, until pH reached 4.5. The product was then cooked at 88°C and 80% RH until internal temperature reached 82°C, and subsequently maintained at 13°C and 80% RH-with frequent measurement of water activity-until target a_w levels (0.90 and 0.85) were achieved (~6 and 24h, respectively). Samples were packaged in heat-sealed PET trilaminate pouches (4 beefsticks in each) from Cadillac Products, Inc. (Troy, MI). Samples for accelerated storage studies were maintained at 52°C and withdrawn after 1, 2, 3 or 4 wk time intervals for analysis.

Mechanical testing

Samples were cored into 1.5 cm dia specimens using a cork borer and sliced to 1.5 cm ht using a razor. Specimens for stress-relaxation tests (Fig. 1) were compressed to 50% strain at a deformation rate of 0.2 mm/min, using a Texture Technologies (Scarsdale, NY) TX2 texture press interfaced with a Zenith 286 computer and allowed to relax (i.e., maintained at constant deformation) for 45s. Force-deformation data were acquired at a rate of 12 points/s and subsequently converted to stress-strain relationships for analysis.

Deformability modulus (E_D), a measure of sample stiffness, was determined according to the procedure of Nussinovitch et al. (1990):

$$E_D = \sigma(t)/\epsilon(t) \qquad [1]$$

in which $\sigma(t)$ is corrected stress (i.e., calculated with accommodation for increases in specimen diameter throughout compression), and $\epsilon(t)$ is Hencky strain.

Asymptotic residual modulus (E_A), from relaxation data at max-

Table 1—Beefstick formulations (g)

Ingredient	Glycerol (0%)	Glycerol (2%)	Glycerol (4%)
Bottom round beef	41,700	40,800	39,900
Glycerol (Penta Mfg)	0	909	1,820
Water	1,360	1,360	1,360
Salt (Morton)	1,330	1,330	1,330
Peppercorn flavor (F&C Intl)	363	363	363
Corn oil (Wesson)	227	227	227
Dextrose (Staley)	227	227	227
Smoke flavor (Red Arrow)	136	136	136
Black pepper (McCormick)	56.8	56.8	56.8
Ascorbyl palmitate (Eastman)	22.7	22.7	22.7
High temperature pediococcus culture (Diversitech)	14.1	14.1	14.1
Ascorbic acid (Eastman)	11.4	11.4	11.4
Tenox GT-2 (Eastman)	9.08	9.08	9.08
Tenox 4A (Eastman)	9.08	9.08	9.08
Sodium nitrite (J.T. Baker)	5.45	5.45	5.45

imum strain and (compressed) sample area (A), was calculated as:

$$E_A = [F_o/A\ \epsilon(1-1/k_2)] \quad [2]$$

in which F_o is initial (unrelaxed) force and k_2–a shape characteristic indicating the relative steepness of the decline in force over time–is determined from the relaxation linearization procedure,

$$F_o t/[F_o-F(t)] = k_1 + k_2 t \quad [3]$$

in which F is force and k_1 a constant. (Nussinovitch et al., 1990). Residual modulus is a measure of the ability of the sample to maintain developed stress over time (t) and is, therefore, an index of "solidity" (Nussinovitch et al., 1990).

Percent recoverable work (Fig 1), indicating ability to rebound from deformation–or "elasticity"– was determined according to the procedure of Kaletunc et al. (1991). Specimens were compressed as described and immediately decompressed at 0.2 mm/s. Percent recoverable work was calculated as the ratio of recoverable work to total work–corresponding to respective areas under the decompression and compression stress-strain functions. Integration was accomplished automatically by the TXT2 texture program. All measurements of modulus, residual modulus and percent recoverable work were conducted in quadruplicate, with each specimen sliced from a different meatstick.

Colorimetry

The relative lightness (L value) of the meatsticks, providing a measure of browning throughout storage, was measured using a Hunter colorimeter. The cut surface of specimens was placed directly in front of the measurement port (dia = 2 cm). Lightness determinations were made in triplicate (using samples from 3 separate meatsticks).

Statistical analysis

Three-way analysis of variance, in which water activity, glycerol content, and storage time were crossed products, was calculated for all results. A Minitab (State College PA) statistical program was used for ANOVA.

RESULTS & DISCUSSION

Deformability modulus

The modulus of the meatsticks decreased markedly with increased moisture –which was ~54% for the 0.90 a_w batch, and 40% for the 0.85 a_w batch, determined by vacuum drying at 60°C [recommended for glycerol-containing products by Hart and Fisher (1971)] for 16 hr–or glycerol (4%), demonstrating the plasticizing effect of either component. Stiffness also decreased with time under accelerated storage (Table 2). Lower water activity samples were about twice firmer than higher a_w samples. The addition of 4% glycerol lowered (initial) modulus by 30% and 43% for the 0.85 and 0.90 a_w samples, respectively. Product firmness was reduced by 29% to 62% during the course of high temperature storage.

A 3-way analysis of variance, in which a_w, glycerol level, and storage time were crossed factors (Table 3), indicated significance of all variables and most cross products ($p<0.01$). Glycerol (4%) lowered (initial) modulus to a greater proportional degree in 0.90 a_w than in 0.85 a_w meatsticks, suggesting a synergistic effect of water and glycerol (but this effect was not maintained throughout storage). Modulus correlated highly with a linear function of a_w, glycerol, and time according to the following equation (r^2 = 84%) derived using Minitab statistical software:

$$\text{modulus} = 3293 - 3418(a_w) - 19.6(\%\ \text{glycerol}) - 29.2(\text{wk}) \quad [4]$$

Decreasing firmness in whole-muscle meat due to increased water and glycerol has been reported by Okonkwo et al. (1992a). Effects in meat emulsion systems (frankfurters) due to glycerol addition were studied by Lacroix and Castigne (1985), who reported a

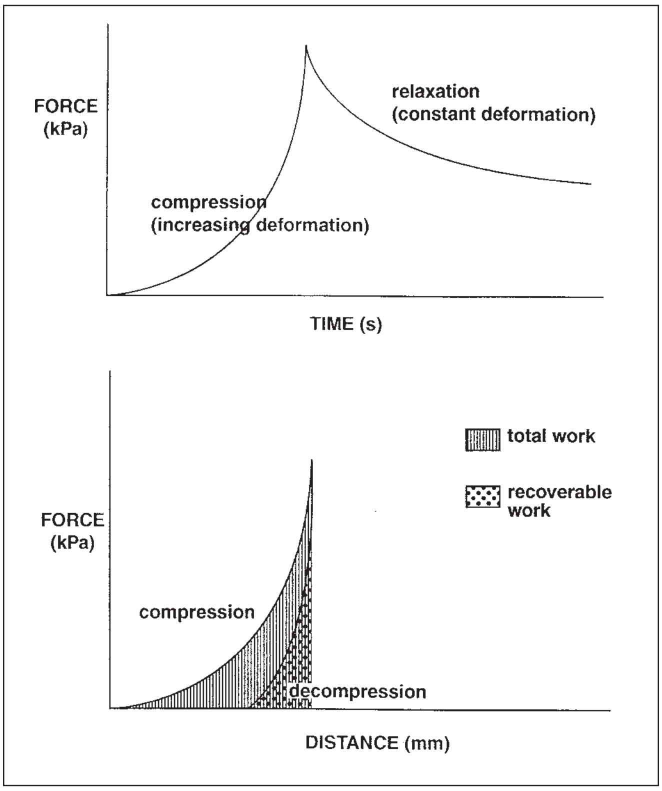

Fig. 1—Schematic (top) compression-relaxation and (bottom) compression-decompression relationships for a processed beefstick product. Modulus is calculated from compression data; asymptotic residual modulus (solidity) is calculated from relaxation data; percent recoverable work is calculated from compression and decompression data–and is equal to the ratio of the areas under the decompression and compression curves, respectively.

Table 2—Deformability modulus (kPa) of processed beefstick product

		Weeks of storage			
Sample	Initial	1	2	3	4
0% glycerol					
0.90 a_w	232±20[a]	137±7	112±7	100±7	93±13
0.85 a_w	425±31	316±28	313±57	290±41	285±27
2% glycerol					
0.90 a_w	262±13	140±18	56±15	102±20	99±15
0.85 a_w	406±13	374±28	263±36	292±27	290±23
4% glycerol					
0.90 a_w	133±19	110±6	71±9	63±16	70±13
0.85 a_w	299±28	218±17	197±29	181±27	182±13

[a]± Standard deviation.

Table 3—ANOVA-Deformability modulus of processed beefstick product

Factor	df[a]	F[b]	p[c]
a_w	1	1560	0.00
Glycerol	2	142	0.00
Storage time	4	124	0.00
a_w ∞ glycerol	2	26.1	0.00
a_w ∞ storage time	4	0.34	0.85
Glycerol ∞ storage time	8	6.05	0.00
a_w ∞ glycerol ∞ storage time	8	2.94	0.01

[a] Degrees of freedom.
[b]Between-groups mean square ÷ within-groups mean square.
[c] Probability that the magnitude of F is attributable to chance.

complex, nonlinear relationship between glycerol level and texture. Their results showed firmness increasing modestly at low glycerol levels, which they attributed in part to glycerol-enhanced emulsion stability, before diminishing at higher glycerol levels.

Our results showed an insignificant influence of glycerol on firmness at 2% (comparison of 0% vs 2% glycerol samples by ANOVA yields p=0.76) with pronounced plasticization evident only at 4% glycerol (Table 3). Glycerol may have some chemical (i.e., reactive) as well as physicochemical effects. Competing effects of glycerol-facilitated cross-linking and glycerol-promoted scission of protein, which can occur at the same time in meat, have been reported (Webster et al., 1982; Ledward et al., 1981; Okonkwo et al., 1992b; Prabhakar et al., 1992). Probably, there is a concentration-dependent and system-specific balance between any discernible structure-enhancing and structure-degrading effects. Note that our observed increases in the mechanical strength of the samples at 2% glycerol were slight compared with the pronounced textural plasticization evident at 4% glycerol. Furthermore, while all samples lost firmness over 4 wk accelerated storage (averaging across water activity), the proportional reductions in modulus were less for 4% glycerol than for 0% glycerol samples (Table 2). Accordingly, ANOVA showed a highly significant glycerol*time interaction term (Table 3).

Residual modulus

Results from relaxation tests were similar to those from compression tests. Residual modulus decreased with either increasing moisture or glycerol (apparent only at 4% glycerol) and also diminished throughout accelerated storage (Table 4). ANOVA revealed significance of all factors and most products (Table 5). Mobility enhancement by either ingredient resulted in abatement of developed stress to lower levels. High water activity and high glycerol content samples showed comparatively greater reductions in relaxation modulus over time, demonstrating that enhanced mobility could accelerate deterioration of sample solidity.

Residual modulus correlated (using Minitab statistical software) with a_w, glycerol level, and storage time by:

$$\text{Solidity} = 2277 - 2374(a_w) - 13.7(\%\ \text{glycerol}) - 23.9(\text{wk}) \quad [5]$$
$$(r^2 = 0.84)$$

Table 4-Asymptotic residual modulus (kPa) of processed beefstick product

		Weeks of storage			
Sample	Initial	1	2	3	4
Glycerol (0%)					
0.90 a_w	134±37[a]	81±11	58±4	50±3	42±6
0.85 a_w	285±27	233±39	197±54	199±18	158±15
Glycerol (2%)					
0.90 a_w	157±6	83±13	48±3	53±4	44±7
0.85 a_w	302±12	219±6	167±7	178±16	154±8
Glycerol (4%)					
0.90 a_w	77±7	54±2	33±7	35±5	31±5
0.85 a_w	205±26	125±21	108±11	126±15	97±6

[a] ±, Standard deviation.

Table 5-ANOVA-Asymptotic residual modulus of processed beefstick product

Factor	df[a]	F[b]	p[c]
a_w	1	1440	0.00
Glycerol	2	132	0.00
Storage time	4	144	0.00
a_w ∞ glycerol	2	28.4	0.00
a_w ∞ storage time	4	5.68	0.00
Glycerol ∞ storage time	8	4.31	0.00
a_w ∞ glycerol ∞ storage time	8	1.08	0.39

[a] Degrees of freedom.
[b]Between-groups mean square ÷ within-groups mean square.
[c]Probability that the magnitude of F is attributable to chance.

Recoverable work

Percent recoverable work was initially higher for the 0.90 a_w samples than for the 0.85 a_w samples. Increased hydration and swelling of the protein matrix probably contributed to elasticity. Recoverable work diminished sharply throughout storage (Table 6). Such reductions in elasticity indicate lessened structural/molecular integration, possibly caused by degradation of, and/or reduced water binding in the protein network. ANOVA (Table 7) showed effects (p<0.01) of water activity and storage time, with a relatively greater reduction in recoverable work in higher moisture (more mobile) samples. The effect of glycerol on elasticity was evident only in interaction terms.

Color

Water activity, glycerol level, and storage time affected product color (Table 8). Samples were darker (p<0.01) with either reduced moisture or glycerol levels (effect of glycerol was most pronounced in 0.85 a_w and unstored samples) and (p<0.1) with increased storage time (Table 9). Proportionally, however, color differences due to glycerol level or storage time were slight compared to those due to moisture content. Darkening as a result of reduced a_w was the only effect discernible by eye. Nonenzymatic browning in meat due to the reactivity of glycerol with protein has been reported by Obanu et al.

Table 6. Percent recoverable work of processed beefstick product

		Weeks of storage			
Sample	Initial	1	2	3	4
Glycerol (0%)					
0.90 a_w	24.6±0.7[a]	17.9±2.0	16.4±0.8	12.6±1.2	18.5±3.0
0.85 a_w	18.1±1.1	14.1±1.2	15.8±0.5	15.0±0.7	18.1±0.6
Glycerol (2%)					
0.90 a_w	26.7±1.8	16.2 ±1.8	15.8±1.8	12.0±1.6	17.3±0.7
0.85 a_w	21.5±0.7	15.5±0.7	15.3±1.0	13.9±1.4	15.8±1.5
Glycerol (4%)					
0.90 a_w	28.2±3.0	14.4±2.5	16.6±1.1	10.7±1.3	15.4±2.9
0.85 a_w	22.4±0.8	14.3±1.1	14.7±1.8	12.1±0.8	15.2±0.6

[a] ± Standard deviation.

Table 7-ANOVA-Percent recoverable work of processed beefstick product

Factor	df [a]	F[b]	p[c]
a_w	1	36.3	0.00
Glycerol	2	1.78	0.17
Storage time	4	158	0.00
a_w ∞ glycerol	2	2.54	0.09
a_w ∞ storage time	4	17.1	0.00
Glycerol ∞ storage time	8	8.20	0.00
a_w ∞ glycerol ∞ storage time	8	1.61	0.13

[a] Degrees of freedom.
[b] Between-groups mean square ÷ within-groups mean square.
[c] Probability that the magnitude of F is attributable to chance.

Table 8-Lightness[a] of processed beefstick product

		Weeks of storage			
Sample	Initial	1	2	3	4
Glycerol (0%)					
0.90 a_w	47.1±3.6[b]	47.2±2.1	46.6±1.2	44.7±0.5	45.1±0.5
0.85 a_w	37.3±0.2	36.1±0.7	37.0±0.8	37.8±0.5	38.6±0.8
Glycerol (2%)					
0.90 a_w	49.6±3.4	47.1±0.9	44.6±1.0	46.4±0.5	45.0±0.2
0.85 a_w	41.0±3.3	39.4±0.4	38.2±1.1	37.7±0.4	38.3±0.8
Glycerol (4%)					
0.90 a_w	47.6±3.4	47.4±0.8	47.4±1.0	46.6±0.9	44.8±0.9
0.85 a_w	41.6±1.5	39.9±1.2	36.4±1.6	37.7±0.1	37.9±1.6

[a]Determined in triplicate as Hunter L value.
[b]± Standard deviation.

Table 9-ANOVA-Lightness[a] of processed beefstick product

Factor	df[b]	F[c]	p[d]
a_w	1	335.	0.00
Glycerol	2	7.58	0.00
Storage time	4	2.07	0.10
$a_w \infty$ glycerol	2	1.00	0.37
$a_w \infty$ storage time	4	0.64	0.64
Glycerol ∞ storage time	8	1.45	0.19
$a_w \infty$ glycerol ∞ storage time	8	1.41	0.21

[a] Determined in triplicate as Hunter L value.
[b] Degrees of freedom.
[c] Between-groups mean squarewithin-groups mean square.
[d] Probability that the magnitude of F is attributable to chance.

(1977); however, that effect was not evident in our beefstick system.

CONCLUSIONS

GLYCEROL FUNCTIONED AS AN EFFECTIVE TEXTURAL PLASTICIZer in processed beefstick products, reducing modulus and structural solidity at the 4% level, with only slight effects on elasticity or color. Sample water activity could be reduced from 0.90 to 0.85 (and stability improved) with a 28% increase in firmness by adding 4% glycerol. By comparison, reduction in a_w effected solely by drying produced an 83% increase in modulus. Textural parameters for all samples declined throughout accelerated storage, but glycerol did not augment the rate of softening. Glycerol provides a means of adjusting textural properties, as well as water activity, in processed meat products. Further research into the sensory or consumer response to such textural changes, as well as the functional benefits of other potential plasticizing constituents, is needed.

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